NASA/TM—2000–209891, Vol. 146

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Shelaine Curd, Editors

Volume 146
BOREAS TE-6 Multiband Vegetation Imager Data

C.J. Kucharik

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

October 2000

The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM—2000–209891, Vol. 146

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Shelaine Curd, Editors

Volume 146

BOREAS TE-6 Multiband Vegetation Imager Data

Christopher J. Kucharik, University of Wisconsin-Madison

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

October 2000

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

BOREAS TE-6 Multiband Vegetation Imager Data

Christopher J. Kucharik

Summary

The BOREAS TE-6 team collected data in support of its efforts to examine the influence of vegetation and climate on the major carbon fluxes in boreal tree species. A newly developed ground-based canopy imaging system called an MVI was tested and used by the BOREAS TE-06 team to collect measurements of the canopy gap fraction (sky fraction), canopy gap-size distribution (size and frequency of gaps between foliage in canopy), branch architecture, and leaf angle distribution (fraction of leaf area in specific leaf inclination classes assuming azimuthal symmetry). Measurements of the canopy gap-size distribution are used to derive canopy clumping indices that can be used to adjust indirect LAI measurements made in nonrandom forests. These clumping factors will also help to describe the radiation penetration in clumped canopies more accurately by allowing for simple adjustments to Beer's law. Measurements of the above quantities were obtained at BOREAS NSA-OJP site in IFC-2 in 1994, at the SSA-OA in July 1995, and at the SSA-OBS and SSA-OA sites in IFC-2 in 1996. Modeling studies were also performed to further validate MVI measurements and to gain a more complete understanding of boreal forest canopy architecture. By using MVI measurements and Monte Carlo simulations, clumping indices as a function of zenith angle were derived for the three main boreal species studied during BOREAS. The analyzed data are stored in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-06 Multiband Vegetation Imager Data

1.2 Data Set Introduction

A newly developed ground-based canopy imaging system called a Multiband Vegetation Imager (MVI) was tested and used during the BOReal Ecosystem-Atmosphere Study (BOREAS) to collect measurements of the canopy gap fraction (sky fraction), canopy gap-size distribution (size and frequency of gaps between foliage in canopy), branch architecture, and leaf angle distribution (fraction of leaf area in specific leaf inclination classes assuming azimuthal symmetry). Measurements of the canopy gap-size distribution are used to derive canopy clumping indices that can be used to adjust indirect leaf area index (LAI) measurements made in nonrandom forests. These clumping factors will also help to describe the radiation penetration in clumped canopies more accurately by allowing for simple adjustments to Beer's law. All of these quantities are essential in performing accurate modeling studies of the exchange of carbon dioxide, water, and heat between the boreal forest and the atmosphere.

The MVI is the combination of a charge-coupled device (CCD) camera, a two-band filter exchange mechanism (visible 400-620 nm and near-infrared 720-950 nm), and a laptop computer, and is powered by a DC to AC inverter and sealed lead acid batteries. The MVI is used to capture rapid, successive images of plant canopies in two wavelength bands. The first image is taken in the visible wavelength band, and the second in the near-infrared band. The purpose of using two wavelength bands is to allow for identification of sunlit and shaded LAI, branch area, clouds, and blue sky based upon the camera's resolution (16 bit) and the varying spectral properties that canopy components have in the two wavelength bands being used. By classifying these images into the above categories, the MVI can be used as a tool to help quantify the canopy structure in terms of leaf angle distribution, LAI, sunlit and shaded LAI, branch architecture, and clumping effects (foliage spatial distributions). This approach is different from other canopy imaging systems (such as fisheye photography) because it allows for rapid acquisition of a digitized two-band image pair that can be used in a variety of sky conditions. The entire process of capturing an image pair is on the order of 50 ms (see Chapter 2; Kucharik, 1997).

This data set provides values of the zenith canopy gap fraction, indirect LAI and total LAI estimates, branch area visible from below the canopy and the spatial distribution of branches, and canopy clumping indices derived from canopy gap-size distributions (measured toward the canopy zenith) in the canopies of BOREAS Southern Study Area (SSA) Old Black Spruce (OBS), SSA Old Aspen (OA), and Northern Study Area (NSA) Old Jack Pine (OJP). The MVI generally measures only a small amount of stem area; thus, stems are considered to be negligible in the total measurement of woody area derived from image data. The canopy gap-size distribution and clumping factors are for scales greater than or equal to the smallest element size the MVI is able to resolve; in conifers, the basic and smallest element size measured by the MVI is a shoot, and in deciduous canopies (aspen), the basic element size is a leaf. An additional clumping factor is needed in conifers to describe the clumping of needles on shoots. The canopy leaf angle distribution for SSA OA was derived from measurements of the light distribution over sunlit leaves coupled with modeling results (Kucharik et al., 1997a).

1.3 Objective/Purpose

One purpose of this study was to determine how Beer's law could be adjusted in a simplistic manner so that it could be applied to nonrandom forest canopies. This would allow for indirect LAI measurement biases to be understood and would provide a means to adjust ecological models that use the Beer-Lambert law to describe the penetration of radiation as a function of angle. Furthermore, because many coniferous species are highly efficient at using diffuse light to perform photosynthesis, accurate characterization of the diffuse light environment in canopies is also necessary. Because the same law (Beer's) applies to direct and diffuse radiation, clumping effects as a function of sun angle need to be properly characterized. Detailed canopy architecture information obtained with the MVI would allow for more accurate modeling and scaling studies to be performed for the BOREAS region.

The development of the MVI was justified by the need to make measurements of the architecture of plant canopies. Studying plant canopy architecture is important to many fields of research, including ecology, forestry, meteorology, and other agricultural sciences. Leaf angle distribution, sunlit LAI, shaded LAI, and clumping factors are quantities that are important to exchanges of energy, water, and carbon in forests. Many indirect architectural measurements obtained in forests assume that the spatial distribution of foliage elements (wood, leaves, shoots, needles) is random. These assumptions often lead to measurement and modeling errors of clumped forest canopies that are typical of the boreal region and of many other coniferous species around the world.

The MVI has the ability to measure the sunlit fraction of LAI with respect to sun zenith angle, and thus the ability to provide essential information for scaling photosynthesis and carbon fixation from the leaf to larger scales. Canopy structure influences many biophysical processes in forests, and virtually all models that attempt to quantify plant-environment interactions, such as effects of climate change on boreal-forest carbon budgets, require the kind of information that is provided by the MVI.

An important finding of this study shows that in clumped boreal forest canopies (all boreal species examined in this study exhibit some varying degrees of grouping of foliage at different scales), the transmission of radiation through the canopy can be coupled to clumping indices that are a function of view angle through the canopy. One single clumping index does not accurately describe the foliage distribution as a function of view angle through the canopy. This will be essential in adjusting indirect LAI measurements made using gap fraction inversion techniques that assume a random spatial foliage distribution. Furthermore, multi-angular clumping factors also allow for the Beer-Lambert law to be adjusted in a simple manner so that it can be applied to nonrandom forest canopies. This adjustment will aid in the most accurate modeling of the radiation regime (direct and diffuse) in nonrandom forest canopies (see Kucharik et al., 1997b). By coupling MVI measurements of canopy gap fraction, branch architecture and canopy clumping indices it can also provide an accurate indirect method to determine the canopy hemisurface LAI. This has allowed for theory to be developed to correct indirect LAI measurements obtained with other optical instrumentation that simply measure the canopy gap fraction with the assumption of a random foliage distribution in canopy space. Additionally, MVI measurements made during BOREAS and Monte Carlo simulations of various forest canopy architecture allowed for the derivation of a simple approach that can estimate canopy clumping factors without having detailed information about the canopy gap-size distribution (see Chapter 5; Kucharik, 1997).

1.4 Summary of Parameters and Variables

This data set is divided into two sections. The first part contains point location measurements of the zenith gap fraction (fgap(0)), indirect measurements of LAI (Le(0)) based on gap fraction values, hemisurface branch area visible from below the canopy (Be), foliage clumping indices obtained from canopy gap-size distribution measurements made toward the zenith (Omega(0)), and estimates of the total hemisurface LAI (L). The second part contains average values of the quantities of Le(0), L, and Omega(0) for each forest area studied (at some BOREAS sites, more than one general area was measured within the site) and provides estimates of the total hemisurface branch area (B) (no stems) and the fraction of Le(0) that is branch area that blocks gaps in the canopy (fb). These branches are not shaded by leaf area (i.e., needles, shoots, or leaves) and thus bias indirect LAI measurements obtained from gap fraction values. Measurements of fb were made during the middle of the growing season (July) when LAI was highest.

1.5 Discussion

The MVI was used to measure canopy gap fraction (LAI), branch architecture, and foliage spatial distributions to characterize spatial variation between species and within species in the boreal region. Furthermore, these key quantities are essential input to models that are used to study the exchange of carbon dioxide, heat, and water vapor between forests and the atmosphere. Measurements were made along transects used by other BOREAS science groups and within allometric plots so that specific comparisons could be performed. Reported data quality is considered excellent except for some branch area measurements reported for NSA OJP that were influenced by forest fires in 1994. Data for NSA

OJP are considered adequate, but not of the highest possible quality compared to the other data sets. Some viewed branch area data are missing for several image locations because of a low confidence level in image classification results at all three sites (SSA OA, NSA OJP, SSA OBS). Because the MVI captures image pairs of canopies at a small scale (i.e., meters), some image locations contain little or no canopy overstory, which prevented a clumping factor from being calculated for a few image locations at NSA OJP and SSA OBS.

1.6 Related Data Sets
BOREAS RSS-07 LAI, Gap Fraction, and fPAR data
BOREAS TE-18 Landsat TM Physical Classification image of the SSA
BOREAS TE-18 Biomass Density Image of the SSA
BOREAS TE-18 Landsat TM Physical Classification Image of the NSA

2. Investigator(s)

2.1 Investigator(s) Name and Title
Dr. Christopher J. Kucharik
Research Associate
University of Wisconsin-Madison
Department of Soil Science

Dr. John M. Norman
Professor
University of Wisconsin-Madison
Department of Soil Science

2.2 Title of Investigation
Measurement and Scaling of Carbon Budgets for Contrasting Boreal Forest Species

2.3 Contact Information

Contact 1:
Dr. Christopher J. Kucharik
University of Wisconsin-Madison
Dept. of Soil Science
1525 Observatory Drive
Madison, WI 53706
(608) 262-0415
(608) 265-2595 (fax)
kucharik@bob.soils.wisc.edu

Contact 2:
Dr. John M. Norman
University of Wisconsin-Madison
Dept. Of Soil Science
1525 Observatory Drive
Madison, WI 53706
(608) 262-4576
(608) 265-2595 (fax)
norman@calshp.cals.wisc.edu

Contact 3:
Shelaine Curd
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-2447
shelaine.curd@gsfc.nasa.gov

3. Theory of Measurements

In order to study the exchange of carbon dioxide, heat, and water vapor between the atmosphere and a forest, proper characterization of the interception of sunlight is essential because of its coupling to canopy photosynthesis, which controls the assimilation of carbon dioxide and release of H_2O back into the atmosphere. The most important factors that influence light transmission in forest canopies are the amount of leaf surface area that intercepts beam radiation and the distribution of foliage elements in canopy space. In many previous studies, the amount of surface area of foliage that is able to exchange CO_2 and H_2O with the atmosphere has been measured using direct, destructive methods, while the spatial distribution of foliage is typically assumed to be random. Because destructive measurements are generally time consuming and restricted in many areas, new instruments have been developed that can estimate LAI using only light transmission measurements made at various view angles from above or below vegetative canopies. Typically, the Beer-Lambert law is used to invert a value of LAI using these gap fraction measurements. Unfortunately, this technique assumes that the foliage elements in space are randomly distributed. Furthermore, these instruments are unable to distinguish between green or leafy foliage (photosynthetically active) and branches. Thus, the LAI obtained from gap fraction measurement techniques may include the effects of light intercepting branch area in the canopy. Therefore, some estimate of this bias is necessary to adequately adjust indirect measurements.

In many conifer stands and all of the boreal species examined in this study, foliage is typically clumped. This phenomenon generally causes indirect leaf area measurements to be underestimated compared to the actual leaf area present. Furthermore, algorithms that are used to calculate sunlit and shaded leaf area fractions as a function of angle (i.e., Beer's law) will also yield inaccurate results if randomness is assumed for a clumped forest. Typically, these algorithms are a part of large-scale models that are used to study the functioning of the entire forest biome. Therefore, corrections must be applied to Beer's law to account for canopy nonrandomness and branch or stem area that intercepts light in forest canopies and biases indirect measurements of LAI. Direct measurements may provide accurate measurements of LAI but are unable to lend any data on the spatial distribution of the various foliage components in the canopy and how they might intercept incoming solar radiation over the course of a day.

With the advent of the MVI, it is now possible to characterize canopy foliage distributions, characterize the spatial relationship of photosynthetically active foliage and woody components, and measure canopy gap fraction values. Because the MVI uses two wavelength bands, specific foliage classes (sunlit/shaded LAI, branches, sky, clouds) can be identified at a small scale. Using image processing algorithms, the canopy gap fraction and canopy gap-size distribution can be determined. Using canopy clumping factors derived from gap-size distribution measurements, adjustments to indirect leaf area values can be applied. However, because of image pixel resolution problems, the MVI cannot resolve (measure) individual needles in conifers because they are typically only a few millimeters wide; thus, the clumping index reported is for scales greater than or equal to the smallest measured element size, which is a shoot. An additional clumping factor (within-shoot) is used to characterize the clumping of needles on shoots in coniferous canopies. Additional image processing is able to determine the amount of branch area that intercepts light in the canopy and biases gap fraction measurements used to determine LAI. In aspen, the near-infrared image band is used to study the light distribution present over sunlit leaves in the canopy and is compared with Monte Carlo simulations to provide an estimate of the canopy leaf angle distribution (see Kucharik et al., 1997a, 1997b).

4. Equipment

4.1 Sensor/Instrument Description

SpectraSource, Inc., CCD camera with Texas Instruments silicon detector (TC-213b; frame transfer) cooled by Peltier coolers and controlled by a 16-bit adapter card; two-band filter exchange mechanism controlled by solenoid, 24-mm Nikon camera lens with minimal antireflection coatings, laptop computer and docking station (contains control card), tripods, powered by sealed lead acid batteries and DC to AC power inverter; 50-ft. of associated cables; 100-MB Zip drive used to store image pairs that are 2 MB each. An HP-9000 workstation was used for all image processing work (see Kucharik et al., 1997b, for a more detailed instrumentation description).

4.1.1 Collection Environment

Data were collected under varied sky conditions, from completely overcast to completely clear. Some data were collected under smoky conditions. At NSA OJP, data were collected under clear to smoky conditions; at SSA OBS under clear to partly cloudy sky conditions; and at SSA OA, in clear to partly cloudy sky conditions. Data were collected when wind speed was minimal (< 5 m/s); however, in some cases, this was not possible, and data quality can be influenced under particularly windy conditions because of slight foliage movements between the visible and near-infrared band exposures. The instrument was not operated under rainy conditions or temperatures under 45 °F. The camera was pointed toward the canopy zenith positioned at a height of 1.5 m above ground level; each image (band) represents a 5-m x 10-m canopy area in aspen and a 3.5-m x 7-m canopy area in black spruce and jack pine. Each image is 512 x 1024 pixels where 1 pixel represents 1 cm at a distance of 10 m from the camera. The camera lens field-of-view (FOV) is 15 x 30 degrees; thus, all digitized image pairs represent canopy areas within 15 degrees of the canopy zenith. All area parameters are expressed on a hemisurface area basis.

4.1.2 Source/Platform

The CCD camera was mounted on a tripod at a height of 1.5 m looking upward toward the canopy zenith.

4.1.3 Source/Platform Mission Objectives

The overall goal was to capture image pairs of boreal forest canopies and identify the canopy gap fraction, LAI, branch area, and canopy gap-size distribution by partitioning image data into sunlit and shaded foliage pixels, branch pixels, and sky pixels. Theory will be combined with canopy gap-size distribution measurements to obtain canopy clumping indices.

4.1.4 Key Variables

- Canopy gap fraction
- indirect leaf area index
- canopy hemi-surface branch area
- light intercepting branch area
- canopy clumping factors
- leaf angle distribution in aspen

4.1.5 Principles of Operation

Script language was programmed to control the solenoid and the operation of the camera system so that a two-band image pair (digitized) within 15 degrees of the canopy zenith was obtained in about 50 ms. The exposure time of each band and the delay between exposures was adjusted accordingly within the script language to adjust to changing environmental conditions (light and wind).

4.1.6 Sensor/Instrument Measurement Geometry

The camera system was mounted on a tripod at a height of 1.5 m above the ground pointed directly toward the canopy zenith using leveling devices. The solar disk was blocked from the camera lens using an object to shade the lens; image pairs were captured between wind gusts to minimize foliage movements between the visible and near-infrared exposures. Any foliage within 3 m of the ground that interfered with measurement of the overstory was moved so that the camera lens had a clear view of the forest canopy. Each image pair is 512 x 1024 pixels and represents a canopy section that was within 15 degrees of the zenith from the camera location vantage point (24-mm lens has an FOV of 15 x 30 degrees).

4.1.7 Manufacturer of Sensor/Instrument

SpectraSource Instruments
31324 Via Colinas, Suite 114
Westlake Village, CA 91362
(818) 707-9035

A filter exchange mechanism was developed by investigators (See Kucharik et al., 1997b).

4.2 Calibration

Calibration was necessary for the gain and bias of the silicon detector. The gain was determined in May 1994 using a flat halon plate (1.5 m x 1.5 m) uniformly illuminated under sunny sky conditions (calibration performed outside). Each image pixel's relative response was determined and applied to each image taken with the MVI system. The bias of the silicon detector (dark pixel current) is temperature dependent. The camera was used only when an optimum temperature of 249 K was obtained by running the camera coolers for 15-30 minutes before data collection. A dark pixel image was typically collected with each data set and was subtracted from each image accordingly.

4.2.1 Specifications

Gain calibration is temperature dependent (detector) (see Kucharik et al., 1997b, for graph of calibration).

4.2.1.1 Tolerance

None.

4.2.2 Frequency of Calibration

Gain calibration was performed at the laboratory in May 1994; dark pixel bias was obtained each day that data were collected.

4.2.3 Other Calibration Information

None.

5. Data Acquisition Methods

The camera system was mounted on a tripod at a height of 1.5 m above the ground pointed directly toward the canopy zenith using leveling devices. The solar disk was blocked from the camera lens using an object to shade the lens; image pairs were captured between wind gusts to minimize foliage movements between the visible and near-infrared exposures. Any foliage within 3 m of the ground that interfered with measurement of the overstory was moved so that the camera lens had a clear view of the forest canopy. Each image pair is 512 x 1024 pixels and represents a canopy section that was within 15 degrees of the zenith from the camera location vantage point (24-mm lens has a FOV of 15 x 30 degrees).

Please refer to the following sources for more complete documentation: Kucharik et al., 1997a and 1997b; Kucharik, 1997.

6. Observations

6.1 Data Notes

Because smoky conditions existed during Intensive Field Campaign (IFC)-2 1994, some image pairs do not have branch area data because image processing algorithms could not distinguish between leafy foliage and branches or stems. Additional branch classification problems were caused by moss and lichens growing on woody material at NSA OJP and SSA OBS. These missing data values are reported as -999 in the data set. Some image locations at NSA OJP and SSA OBS had little or no foliage present in the camera FOV; this prevented canopy clumping indices from being derived for these image locations denoted by -999 in the data set.

6.2 Field Notes

One large bear confronted S.T. Gower during IFC-2 1996 at SSA-OBS.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Measurement (camera) locations were spaced at each site by 3 m along the ground (position of tripod) so that there was at least 1 m of overlap (between successive images) in the actual canopy area measured.

Measurement site descriptions and the North American Datum of 1983 (NAD83) coordinates of the sites are:

- NSA-OJP flux tower site, Lat/Long: 55.842°N, 98.62°W.

Measurements were made within Terrestrial Ecology (TE)-23's plot and along Transect B set up by Remote Sensing Science (RSS)-07. A total of 50+ image pairs, each covering approximately 25 m^2 of canopy area, were collected within the plot and along Transect B. Therefore, approximately 1000 m^2 of total canopy area was digitized and analyzed at this site. Seven additional image pairs each were collected in one plot of TE-06 without alder (Plot1 NA) and on one plot with alder growing (Plot2Alder).

- SSA-OBS flux tower site, Lat/Long: 53.987°N, 105.12°W.

A total of 30 image pairs were taken along Transect B from 40 m to 120 m away from the flux tower, spaced approximately 3 m apart along the ground. Fifteen image pairs were collected within allometry plot 1 (TE-06), and 15 image pairs were taken within allometry plot 3 (TE-06). Image locations within allometry plots were chosen so that the entire canopy area above the plot was measured. Each image represents a 25 m^2 canopy area measured.

- SSA-OA flux tower site, Lat/Long: 53.629°N, 106.12°W.

A total of 30 image pairs were taken along Transect B (RSS-07) from the flux tower to 105 m to the southwest, spaced approximately 3 m apart along the ground (image locations). Ten image pairs were collected to the north of the flux tower from 2 m to 12 m away from the tower underneath the tramway cable system spaced 1 m apart. Fifteen image pairs were taken within allometry plot 4 (TE-06); image locations were chosen within the plot so that the entire vegetative canopy above the plot could be measured. Each image pair in aspen represents a 50 m^2 canopy area (5 m x 10 m).

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

In conifer species (jack pine and black spruce), one image pixel represents approximately 0.6 cm in the canopy; in aspen, one image pixel represents about 1.0 cm in the canopy. Each image in aspen represents a 5-m x 10-m canopy area; for SSA OBS and NSA OJP, each image represents a 3.5-m x 7-m canopy sectional area. All canopy areas in each image pair represent the area within 15 degrees of the zenith viewed from the position of the CCD camera 1.5 m above the ground.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Images were collected between 8 a.m. and 8 p.m. during summer field campaigns in 1994, 1995, and 1996. Specific dates and times of each measurement are given in the data table. Measurements were made during the middle of the growing season (July) when LAI was highest.

7.2.2 Temporal Coverage Map

Site	Date
NSA OJP (Plot 1-No Alder TE-06)	26-Jul-1994
NSA OJP (Plot 2-Alder TE-06)	26-Jul-1994
NSA OJP (TE-23 plot-Transect B)	29-Jul, 01-Aug-1994
SSA OA (beneath Tram)	02-Jul-1995
SSA OA (Transect B-RSS-07)	14-Jul-1996
SSA OA (Plot 4 TE-06)	14-Jul-1996
SSA OBS(Transect B-RSS-07)	08-Jul-1996
SSA OBS(Plot 1 & 3 TE-06)	09-Jul-1996

7.2.3 Temporal Resolution

Measurements were made at each site on multiple occasions but at irregular time intervals.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

```
BOREAS TE-06 Point multi-band vegetation imager data
         Column Name
------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
TOTAL_LEAF_AREA_INDEX
TOTAL_PLANT_AREA_INDEX
ZENITH_CLUMPING_FACTOR
VISIBLE_BRANCH_AREA_INDEX
ZENITH_GAP_FRACTION
SITE_COMMENTS
CRTFCN_CODE
REVISION_DATE
```

BOREAS TE-06 Mean multi-band vegetation imager data

Column Name
SITE_NAME
SUB_SITE
START_DATE
END_DATE
MEAN_TOTAL_LEAF_AREA_INDEX
MEAN_TOTAL_PLANT_AREA_INDEX
MEAN_ZENITH_CLUMPING_FACTOR
MEAN_TOTAL_BRANCH_AREA_INDEX
MEAN_FRACTION_BRANCHES
SITE_COMMENTS
CRTFCN_CODE
REVISION_DATE

7.3.2 Variable Description/Definition

The descriptions of the parameters contained in the data files on the CD-ROM are:

BOREAS TE-06 Point multi-band vegetation imager data

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE_OBS	The date on which the data were collected.
TOTAL_LEAF_AREA_INDEX	Total hemisurface leaf area derived from indirect LAI measurements and adjusted for branches and nonrandom foliage distributions.
TOTAL_PLANT_AREA_INDEX	Indirect hemisurface leaf area-- includes both woody and leafy foliage components-derived from MVI measurements of fgap(0).
ZENITH_CLUMPING_FACTOR	Zenith canopy clumping factor for scales greater than or equal to the smallest element size (shoots or leaves).
VISIBLE_BRANCH_AREA_INDEX	Indirect hemisurface branch area viewed from below the canopy with the MVI (visible to the camera).
ZENITH_GAP_FRACTION	Zenith canopy gap fraction measured with the CCD camera pointed toward the zenith.
SITE_COMMENTS	Descriptive information to clarify or enhance the site information.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified

	by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).
REVISION_DATE	The most recent date when the information in the referenced data base table record was revised.

BOREAS TE-06 Mean multi-band vegetation imager data

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is
the	
	group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
START_DATE	The date on which the collection of data commenced.
END_DATE	The date on which the collection of the data was terminated.
MEAN_TOTAL_LEAF_AREA_INDEX	Total hemi-surface leaf area derived from indirect LAI measurements and adjusted for branches and nonrandom foliage distributions.
MEAN_TOTAL_PLANT_AREA_INDEX	Indirect hemi-surface leaf area-- includes both woody and leafy foliage components-derived from MVI measurements of fgap(0).
MEAN_ZENITH_CLUMPING_FACTOR	Zenith canopy clumping factor for scales greater than or equal to the smallest element size (shoots or leaves).
MEAN_TOTAL_BRANCH_AREA_INDEX	Total hemi-surface branch area index.
MEAN_FRACTION_BRANCHES	Fraction of Le(0) that is composed of branches that block out gaps in the canopy-i.e. area not shaded by other leafy foliage (shoots or leaves) in the canopy.
SITE_COMMENTS	Descriptive information to clarify or enhance the site information.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).
REVISION_DATE	The most recent date when the information in the referenced data base table record was revised.

7.3.3 Unit of Measurement

The measurement units for the parameters contained in the data files on the CD-ROM are:

BOREAS TE-06 Point multi-band vegetation imager data

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TOTAL_LEAF_AREA_INDEX	[meter^2 leaf][meter^-2 ground]
TOTAL_PLANT_AREA_INDEX	[meter^2 leaf][meter^-2 ground]
ZENITH_CLUMPING_FACTOR	[unitless]
VISIBLE_BRANCH_AREA_INDEX	[meter^2][meter^-2]
ZENITH_GAP_FRACTION	[unitless]
SITE_COMMENTS	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

BOREAS TE-06 Mean multi-band vegetation imager data

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
START_DATE	[DD-MON-YY]
END_DATE	[DD-MON-YY]
MEAN_TOTAL_LEAF_AREA_INDEX	[meter^2 leaf][meter^-2 ground]
MEAN_TOTAL_PLANT_AREA_INDEX	[meter^2 leaf][meter^-2 ground]
MEAN_ZENITH_CLUMPING_FACTOR	[unitless]
MEAN_TOTAL_BRANCH_AREA_INDEX	[meter^2][meter^-2]
MEAN_FRACTION_BRANCHES	[unitless]
SITE_COMMENTS	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

7.3.4 Data Source

The sources of the parameter values contained in the data files on the CD-ROM are:

BOREAS TE-06 Point multi-band vegetation imager data

Column Name	Data Source
SITE_NAME	[BORIS Designation]
SUB_SITE	[BORIS Designation]
DATE_OBS	[Human Observer]
TOTAL_LEAF_AREA_INDEX	[Multiband Vegetation Imager]
TOTAL_PLANT_AREA_INDEX	[Multiband Vegetation Imager]
ZENITH_CLUMPING_FACTOR	[Multiband Vegetation Imager]
VISIBLE_BRANCH_AREA_INDEX	[Multiband Vegetation Imager]
ZENITH_GAP_FRACTION	[Multiband Vegetation Imager]
SITE_COMMENTS	[Human Observer]
CRTFCN_CODE	[BORIS Designation]
REVISION_DATE	[BORIS Designation]

BOREAS TE-06 Mean multi-band vegetation imager data

Column Name	Data Source
SITE_NAME	[BORIS Designation]
SUB_SITE	[BORIS Designation]
START_DATE	[Human Observer]
END_DATE	[Human Observer]
MEAN_TOTAL_LEAF_AREA_INDEX	[Multiband Vegetation Imager]
MEAN_TOTAL_PLANT_AREA_INDEX	[Multiband Vegetation Imager]
MEAN_ZENITH_CLUMPING_FACTOR	[Multiband Vegetation Imager]
MEAN_TOTAL_BRANCH_AREA_INDEX	[Multiband Vegetation Imager]
MEAN_FRACTION_BRANCHES	[Multiband Vegetation Imager]
SITE_COMMENTS	[Human Observer]
CRTFCN_CODE	[BORIS Designation]
REVISION_DATE	[BORIS Designation]

7.3.5 Data Range

The following table gives information about the parameter values found in the data files on the CD-ROM.

BOREAS TE-06 Point multi-band vegetation imager data

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	NSA-OJP-FLXTR	SSA-OBS-FLXTR	None	None	None	None
SUB_SITE	9TE06-PMV01	9TE06-PMV50	None	None	None	None
DATE_OBS	26-JUL-94	14-JUL-96	None	None	None	None
TOTAL_LEAF_AREA_INDEX	.06	12.42	-999	None	None	None
TOTAL_PLANT_AREA_INDEX	.02	4.67	None	None	None	None
ZENITH_CLUMPING_FACTOR	.05	.96	-999	None	None	None
VISIBLE_BRANCH_AREA_INDEX	.05	1.56	-999	None	None	None
ZENITH_GAP_FRACTION	.097	.99	None	None	None	None
SITE_COMMENTS	N/A	N/A	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	27-MAY-98	27-MAY-98	None	None	None	None

BOREAS TE-06 Mean multi-band vegetation imager data

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	NSA-OJP-FLXTR	SSA-OBS-FLXTR	None	None	None	None
SUB_SITE	9TE06-AMV01	9TE06-AMV03	None	None	None	None
START_DATE	26-JUL-94	14-JUL-96	None	None	None	None
END_DATE	29-JUL-94	14-JUL-96	None	None	None	None
MEAN_TOTAL_LEAF_AREA_INDEX	2.9	6.2	None	None	None	None
MEAN_TOTAL_PLANT_	1.2	2.2	None	None	None	None

AREA_INDEX						
MEAN_ZENITH_CLUMPING_FACTOR	.35	.64	None	None	None	None
MEAN_TOTAL_BRANCH_AREA_INDEX	.56	.66	None	None	None	None
MEAN_FRACTION_BRANCHES	.002	.08	None	None	None	None
SITE_COMMENTS	N/A	N/A	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	27-MAY-98	27-MAY-98	None	None	None	None

Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.
Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.
Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but not identical data sets into the same data base table but this particular science team did not measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A -- Indicates that the value is not applicable to the respective column.
None -- Indicates that no values of that sort were found in the column.

7.4 Sample Data Record

The following are wrapped versions of data record from a sample data file on the CD-ROM.

BOREAS TE-06 Point multi-band vegetation imager data

```
SITE_NAME,SUB_SITE,DATE_OBS,TOTAL_LEAF_AREA_INDEX,TOTAL_PLANT_AREA_INDEX,
ZENITH_CLUMPING_FACTOR,VISIBLE_BRANCH_AREA_INDEX,ZENITH_GAP_FRACTION,
SITE_COMMENTS,CRTFCN_CODE,REVISION_DATE
'NSA-OJP-FLXTR','9TE06-PMV01',26-JUL-94,4.0,.77,.21,.453,.68,'Plot1NA','CPI',
27-MAY-98
'NSA-OJP-FLXTR','9TE06-PMV01',26-JUL-94,3.49,1.47,.49,.1,.48,'Plot1NA','CPI',
27-MAY-98
```

```
BOREAS TE-06 Mean multi-band vegetation imager data
SITE_NAME,SUB_SITE,START_DATE,END_DATE,MEAN_TOTAL_LEAF_AREA_INDEX,
MEAN_TOTAL_PLANT_AREA_INDEX,MEAN_ZENITH_CLUMPING_FACTOR,
MEAN_TOTAL_BRANCH_AREA_INDEX,MEAN_FRACTION_BRANCHES,SITE_COMMENTS,CRTFCN_CODE,
REVISION_DATE
'NSA-OJP-FLXTR','9TE06-AMV01',26-JUL-94,29-JUL-94,3.05,1.2,.45,.65,.08,
'Plot 1 TE-6, Plot 2 TE-6, Transect B','CPI',27-MAY-98
'SSA-9OA-FLXTR','9TE06-AMV01',02-JUL-95,02-JUL-95,3.1,1.73,.54,.56,.03,'TRAM',
'CPI',27-MAY-98
```

8. Data Organization

8.1 Data Granularity

The smallest data element tracked by the BOREAS Information System (BORIS) in its handling of the data was the data from a given site on a given day.

8.2 Data Format(s)

The Compact Disk-Read-Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of Hyper-Text Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

9. Data Manipulations

9.1 Formulae

Indirect LAI (Le(0)) estimates are derived using canopy gap fraction measurements and Beer's law:

$$fgap(0) = \exp[-K(0)\, Le(0)/\cos(0)] \quad (1)$$

where K(0) is the canopy extinction coefficient = 0.5

Total LAI values (L) are derived using Le(0) values and adjustments for canopy nonrandomness (clumping factors - Omega(0)) and estimates of the amount of hemi-surface branch area that intercepts light (blocks gaps) in the canopy.

$$L = [Le(0) - b] / Omega(0) \quad (2)$$

where b is the hemisurface branch area that intercepts light in the canopy (not shaded by foliage) and is the within-shoot clumping factor, measured by BOREAS RSS-07 (J.M. Chen, Canadian Centre of Remote Sensing).

For a more detailed description, please refer to Kucharik, 1997 or Kucharik et al., 1997a and 1997b.

9.1.1 Derivation Techniques and Algorithms

Canopy clumping factors (Omega(0)) were calculated using MVI measurements of the canopy gap-size distribution and theory according to Chen and Cihlar, 1995.

Values of L are derived using theory developed as part of C.J. Kucharik's Ph.D. Thesis, University of Wisconsin-Madison, 1997.

9.2 Data Processing Sequence

9.2.1 Processing Steps

- Images are captured with the camera.
- Images are corrected for gain-bias of the detector, and visible and near-infrared bands are registered with each other to account for foliage movements between image exposures.
- An edge enhancement algorithm is applied to each two-band image pair.
- An image classification algorithm is used (Zhang et al., 1996) to partition foliage pixels (branches, stems, leaves, shoots, needles) from sky pixels so the gap fraction can be determined.
- Le(0) is calculated.
- The canopy gap-size distribution is determined; the theory of Chen and Cihlar, 1995 is used to obtain a value of Omega(0).
- Foliage class in each image is reclassified into sunlit/shaded foliage and branch pixels.
- Amount of viewed branch area backed by sky (intercepting light) is determined using another computer algorithm.
- Value of L is determined.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

For aspen (SSA OA), the canopy leaf angle distribution was calculated using MVI measurements of light distribution over sunlit leaves and was compared to Monte Carlo simulations of aspen canopy architecture with various leaf angle distributions (LAD) by implementing a beta distribution. Assuming azimuthal symmetry, the mean leaf angle (MLA) was solved for as being equal to 70° and the two parameters (meu and neu) for the beta distribution were equal to meu=0.56 and neu=2.58.

Please refer to either Kucharik, 1997, Chapter 3, or Kucharik et al., 1997a, for complete details and estimates of the sunlit LAI if interested.

Canopy clumping factors (Omega(0)) were calculated using MVI measurements of the canopy gap-size distribution and theory according to Chen and Cihlar, 1995.

Values of L are derived using theory developed as part of C.J. Kucharik's Ph.D. Thesis, University of Wisconsin-Madison, 1997.

Values of LAI, gap fraction, and Fraction of absorbed Photosynthetically Active Radiation (FPAR) were measured by RSS-07 (J.M. Chen, Canadian Centre of Remote Sensing) and reported in Chen et al., 1997.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Possible measurement errors exist from poor image registrations between visible and near-infrared image bands; classification errors are possible because of mixed pixels (i.e., half sky and half foliage); and assessment of branch area has possible errors because of lichens and moss growing on branches, which prevented proper classification of the underlying structure (branch or stem) as being part of the actual value. Generally, all of these errors are likely to result in an error value of 10% in derived values of gap fraction, gap-size distribution, and branch area.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Comparisons were performed with model simulations, direct LAI measurements (allometric equations/BOREAS TE-06), and clumping factors obtained from BOREAS RSS-07 (J.M. Chen).

10.2.2 Confidence Level/Accuracy Judgment

Data quality is considered very reliable, significant comparisons have been performed as discussed in Section 10.2.1, and reasoning for any disagreement has been explained scientifically and agreed upon.

10.2.3 Measurement Error for Parameters

There is a possible 10% error with values of indirect hemisurface branch area (Be), fraction of the indirect hemisurface leaf area (fb), the fraction of the indirect hemisurface leaf-area (Le(0)), the indirect hemisurface leaf-area (L) and the zenith canopy clumping factor (Omega(0)) because of possible classification errors and other problems discussed in Section 10.1.

10.2.4 Additional Quality Assessment

Results have been examined carefully for bias patterns and outliers. The data set presented is considered preliminary at this time.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of Data

None.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

None.

11.4 Other Relevant Information

One large bear confronted S.T. Gower during IFC-2 1996 at SSA-OBS.

Because of the complexity and actual usage of the MVI, any questions regarding specific image processing, data manipulation, or construction of the instrument should be directed to:

Dr. Christopher J. Kucharik
University of Wisconsin-Madison
Department of Soil Science
1525 Observatory Drive
Madison, WI 53706
(608) 262-0415
kucharik@bob.soils.wisc.edu

The most comprehensive, detailed description of the instrument and how data are derived can be found in Kucharik, 1997 (Ph.D. Thesis, available on microfilm from archives at University of Michigan-Ann Arbor) and Kucharik et al., 1997b.

12. Application of the Data Set

The data can be used for the study of plant canopy architecture.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

Some calculations were performed using MS Excel for Windows 5.0 and Spyglass Plot. Image analysis were performed using the principal investigators' original algorithms.

14.2 Software Access

Contact Dr. Christopher J. Kucharik (see Section 2.3 or 11.4) if interested.

15. Data Access

The MVI data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series. Actual MVI raw image pairs in FITS or TIFF format for the various sites are available upon request. Contact Dr. Christopher J. Kucharik listed in Section 2.3 or 11.4.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

None.

17.2 Journal Articles and Study Reports

Chen, J.M. and J. Cihlar. 1995. Quantifying the effect of canopy architecture on optical measurements of leaf area index using two gap size analysis methods. IEEE Trans. Geosci. Remote Sens., 33: 777-787.

Chen, J.M., P.M. Rich, S.T. Gower, J.M. Norman, and S. Plummer. 1997. Leaf area index of boreal forests: Theory, techniques, and measurements. Journal of Geophysical Research 102(D24):29,429-29,443.

Kucharik, C.J. 1997. Characterizing the radiation regime in nonrandom forest canopies. Ph.D. Thesis, University of Wisconsin-Madison, 308 pp.

Kucharik, C.J., J.M. Norman, and S.T. Gower. 1997a. Measurements of leaf orientation, light distribution, and sunlit leaf area in boreal aspen. Submitted to Agricultural and Forest Meteorology.

Kucharik, C.J., J.M. Norman, and S.T. Gower. 1998a. Measurements of leaf orientation, light distribution, and sunlit leaf area in a boreal aspen forest. Agricultural and Forest Meteorology 91(1-2): 127-148.

Kucharik, C.J., J.M. Norman, and S.T. Gower. 1998b. Measurements of branch area and adjusting leaf area index indirect measurements. Agricultural and Forest Meteorology, 91 (1-2): 69-88.

Kucharik, C.J., J.M. Norman, L.M. Murdock, and S.T. Gower. 1997b. Characterizing canopy nonrandomness with a multiband vegetation imager (MVI). Journal of Geophysical Research 102(D24):29,455-29,473.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

Zhang, T., R. Ramakrishnan, and M. Livny. 1996. BIRCH: An efficient data clustering method for very large databases. In Proc. of ACM SIGMOD International Conf. on Data Management, June 1996, Montreal, Canada.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

```
B          - Total hemisurface branch area index
Be         - Indirect hemisurface branch area viewed from below the canopy
             with the MVI (visible to camera)
Fb         - Fraction of Le(0) that is composed of branches that block out gaps
             in the canopy; i.e., are not shaded by other leafy foliage (shoots
             or leaves) in the canopy
fgap(0) - Zenith canopy gap fraction measured with the CCD camera pointed
             toward the zenith
L          - Total hemisurface leaf area derived from indirect LAI
             measurements and adjusted for branches and nonrandom foliage
             distributions
Le(0)      - Indirect hemisurface leaf area; includes both woody and leafy
             foliage components; derived from MVI measurements of fgap(0)
Omega(0)- Zenith canopy clumping factor for scales greater than or equal to
             the smallest element size (shoots or leaves).
```

19. List of Acronyms

```
ASCII   - American Standard Code for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
CCD     - Charge-Coupled Device
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
FOV     - Field of View
FPAR    - Fraction of absorbed Photosynthetically Active Radiation
GIS     - Geographic Information System
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
IFC     - Intensive Field Campaign
LAD     - Leaf Angle Distribution
LAI     - Leaf Area Index
MLA     - Mean Leaf Angle
MVI     - Multiband Vegetation Imager
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
OA      - Old Aspen
OBS     - Old Black Spruce
OJP     - Old Jack Pine
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
RSS     - Remote Sensing Science
SSA     - Southern Study Area
TE      - Terrestrial Ecology
URL     - Uniform Resource Locator
```

20. Document Information

20.1 Document Revision Date
Written: 28-May-1997
Last Updated: 26-Jul-1999

20.2 Document Review Date
BORIS Review: 23-Jun-1998
Science Review: 24-Jun-1998

20.3 Document ID

20.4 Citation
When using these data, please contact the investigators listed in Section 2.3 and cite relevant papers in Section 17.2.

If using data from the BOREAS CD-ROM series, also reference the data as:

Kucharik, C.J. and J.M. Norman, "Measurement and Scaling of Carbon Budgets for Contrasting Boreal Forest Species." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2000	Technical Memorandum

4. TITLE AND SUBTITLE

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS TE-6 Multiband Vegetation Imager Data

5. FUNDING NUMBERS

923
RTOP: 923-462-33-01

6. AUTHOR(S)

Christopher J. Kucharik
Forrest G. Hall and Shelaine Curd, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)

Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER

2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

TM—2000–209891
Vol. 146

11. SUPPLEMENTARY NOTES

C.J. Kucharik: University of Wisconsin-Madison;
S. Curd: Raytheon ITSS, NASA Goddard Space Flight Center, Greenbelt, Maryland

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-6 team collected data in support of its efforts to examine the influence of vegetation and climate on the major carbon fluxes in boreal tree species. A newly developed ground-based canopy imaging system called an MVI was tested and used by the BOREAS TE-06 team to collect measurements of the canopy gap fraction (sky fraction), canopy gap-size distribution (size and frequency of gaps between foliage in canopy), branch architecture, and leaf angle distribution (fraction of leaf area in specific leaf inclination classes assuming azimuthal symmetry). Measurements of the canopy gap-size distribution are used to derive canopy clumping indices that can be used to adjust indirect LAI measurements made in nonrandom forests. These clumping factors will also help to describe the radiation penetration in clumped canopies more accurately by allowing for simple adjustments to Beer's law. Measurements of the above quantities were obtained at BOREAS NSA-OJP site in IFC-2 in 1994, at the SSA-OA in July 1995, and at the SSA-OBS and SSA-OA sites in IFC-2 in 1996. Modeling studies were also performed to further validate MVI measurements and to gain a more complete understanding of boreal forest canopy architecture. By using MVI measurements and Monte Carlo simulations, clumping indices as a function of zenith angle were derived for the three main boreal species studied during BOREAS. The analyzed data are stored in tabular ASCII files.

14. SUBJECT TERMS	15. NUMBER OF PAGES
BOREAS, terrestrial ecology, vegetation imager data.	22
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL